The Surface of Mars

3. Light and Dark Markings[1]

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The Mariner 6 and 7 pictures have provided significant clues to the nature of the light and dark markings on Mars, but do not yet provide an adequate foundation for any complete explanation of the phenomena. They display detail never before seen or photographed and demonstrate that there is no network of dark lines (i.e. canals) on the planet. A variety of shapes and of boundaries between major markings are recorded in the pictures. No substantial correlation of albedo markings with cratered or chaotic terrain has been recognized; featureless terrain conceivably may be genetically related to light areas. Within and surrounding the dark area Meridiani Sinus there is evidence of local topographic control of albedo markings, light material is found in locally low areas. Also, characteristic patterns of local albedo markings are exhibited by craters there. Aeolian transportation of light material with deposition locally in low areas is suggested as an explanation of these markings and may be useful as a working hypothesis for subsequent exploration. Across some light/dark boundaries crater morphologies are unchanged; across others craters in the light area appear smoother. If there is a relationship between cratered-terrain modification and surface albedo it is an indirect one.

In 1965, the Mariner 4 spacecraft transmitted to earth the first close-up pictures of Mars revealing a heavily cratered surface. Because of their limited areal coverage, these pictures added little to our knowledge of the light and dark surface markings that have been viewed and photographed by astronomical observers. In particular, they failed to resolve the controversy over the existence of the Martian canal network, a pattern of fine dark lines spanning the surface of the planet that has been reported by many visual observers. In 1969, Mariner 6 and 7 returned to earth more than 200 pictures that show more clearly the light and dark features known previously, display markings never before reported, yet reveal no suggestion of a network of thin dark lines.

This is the third of a coordinated series of four articles about the surface features of Mars that comprise part of the final report of the Mariner '69 TV team. In this article, first the Mariner far-encounter pictures are compared with earth-based photographs and maps of visual observers, and the regional character of light/dark markings is considered. Then the near-encounter pictures of Mariners 6 and 7 in the Meridiani Sinus area are analyzed for evidence of the physical nature of the light and dark markings there. The objective of this paper is principally to call attention to some of the relevant observations in the pictures, not to attempt any complete explanation of the albedo variations on Mars.

The morphology and distribution of topographic forms on the surface of Mars have been discussed in the first two articles on surface features, *Murray et al.* [1971] and *Sharp et al.* [1971]. Some familiarity with the contents of these two articles is assumed. Data concerning flight paths, details of TV camera systems, and other such information are given in an earlier presentation [*Leighton et al.*, 1969] and in the paper by Leighton and Murray earlier in this issue [*Leighton and Murray*, 1971].

FAR-ENCOUNTER OBSERVATIONS

Comparison with earth-based observations. Mariner 6 and 7 far-encounter images provided views of the entire planetary disk. In Figures

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1*a* and 1*b*, these are compared with photographs obtained at New Mexico State University Observatory (NMSU) within 2 months of encounter. The fine detail shown in the Mariner photographs, but not discernible in the NMSU pictures, permits a more reliable evaluation of the nature of oases, canals, and the nature of light/dark boundaries than was previously possible.

A useful display of Mariner 6 and 7 far-encounter photographs has been prepared by transforming parts of individual far-encounter images into Mercator projection and compiling these into a Mercator photomap similar in form

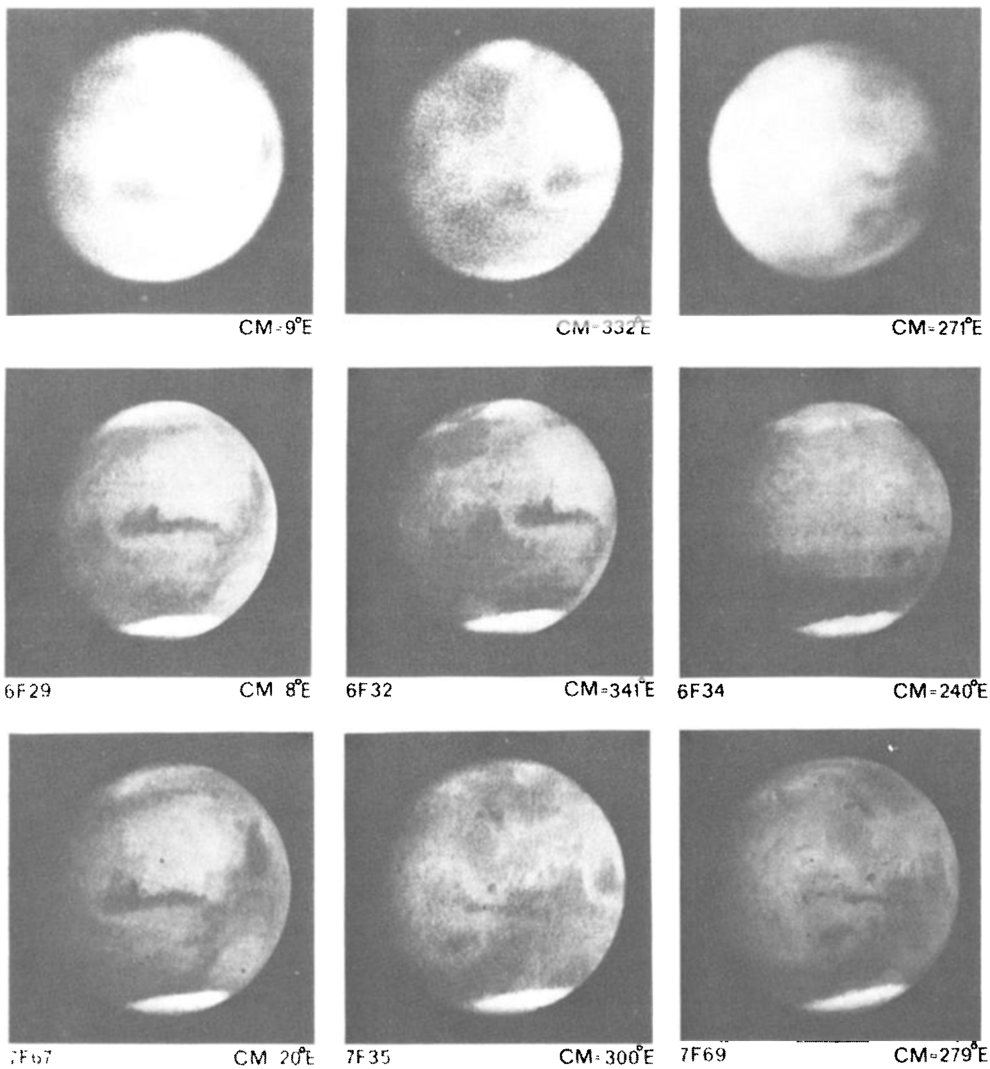

Fig. 1*a*.

Figure 1 shows a comparison between Mariner and earth-based photographs. Images in the top row were obtained at the observatory of New Mexico State University. They were taken in green light and closely match the spectral response of the Mariner B cameras used in obtaining the images shown in the middle (Mariner 6) and bottom (Mariner 7) rows. The viewing geometry was different for the Mariner and NMSU photographs, the center of the disk being at 5°S and 5°N, respectively. The central meridian (CM) is given in east longitude for each image.

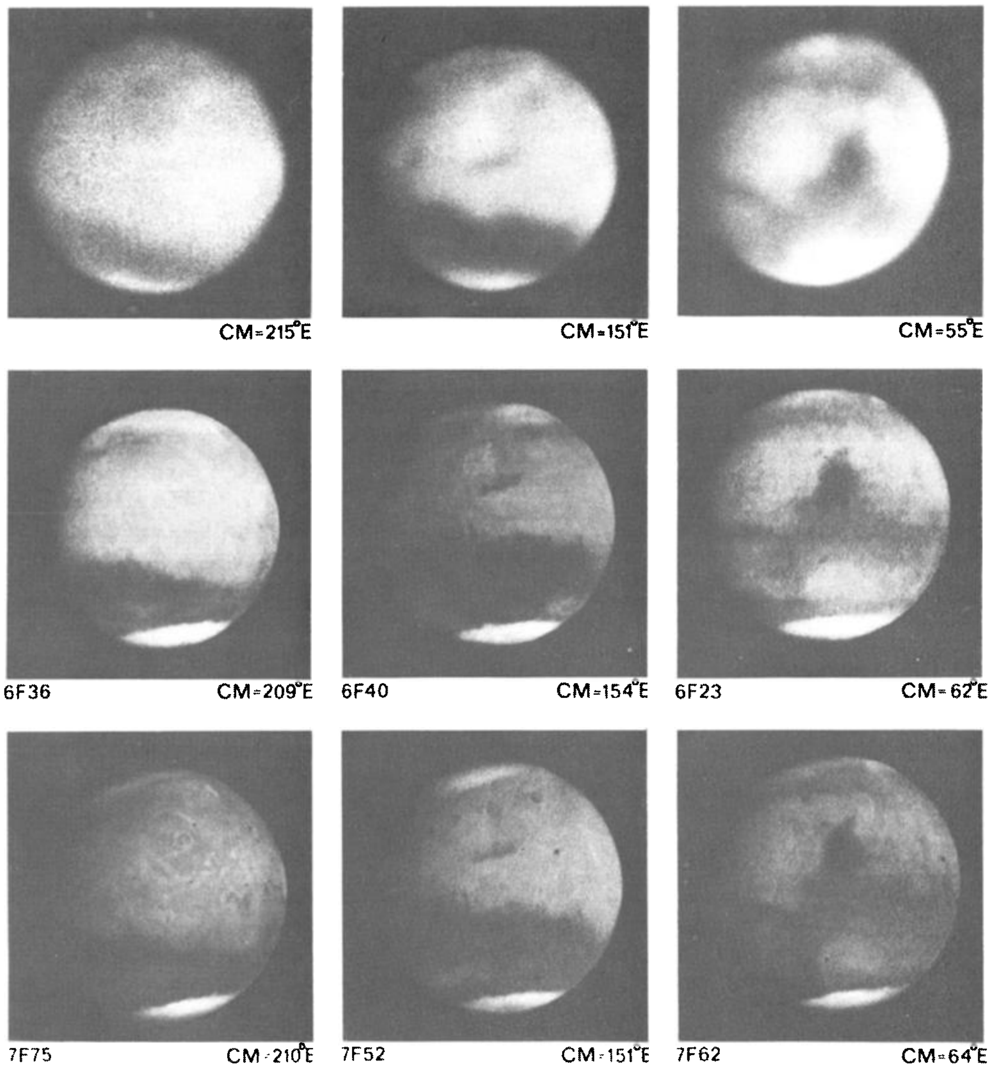

Fig. 1b.

to those used to display earth-based observations (Figure 2) [*Cutts et al.*, 1971]. Earth-based observations (photographic and visual) and scientific implications of those observations are re-evaluated here in light of the Mariner 6 and 7 data.

It has been stated by many visual observers that for the purpose of recording fine detail on the surface of Mars, sketches of visual observations are superior to photographic records. Drawings made by visual observers have been used, for example, to provide the fine detail in the maps of Mars (Figure 3). Common in such maps is a complex network of fine dark lines linking small dark nodes and major dark features. Some scientists have questioned the existence of the networks, attributing them to the physiology of the human eye, and thus there still remains some controversy over their reality and meaning.

We can clearly establish the superiority of the Mariner 6 and 7 pictures over visual records by a comparison of the Mariner Mercator photomap (Figure 2) with the ACIC map (Figure 3). In the Mariner map, complex fine detail is visible in the areas of Nix Olympica, Agathodaemon, Trivium Charontis, and Aethiopis. In the cor-

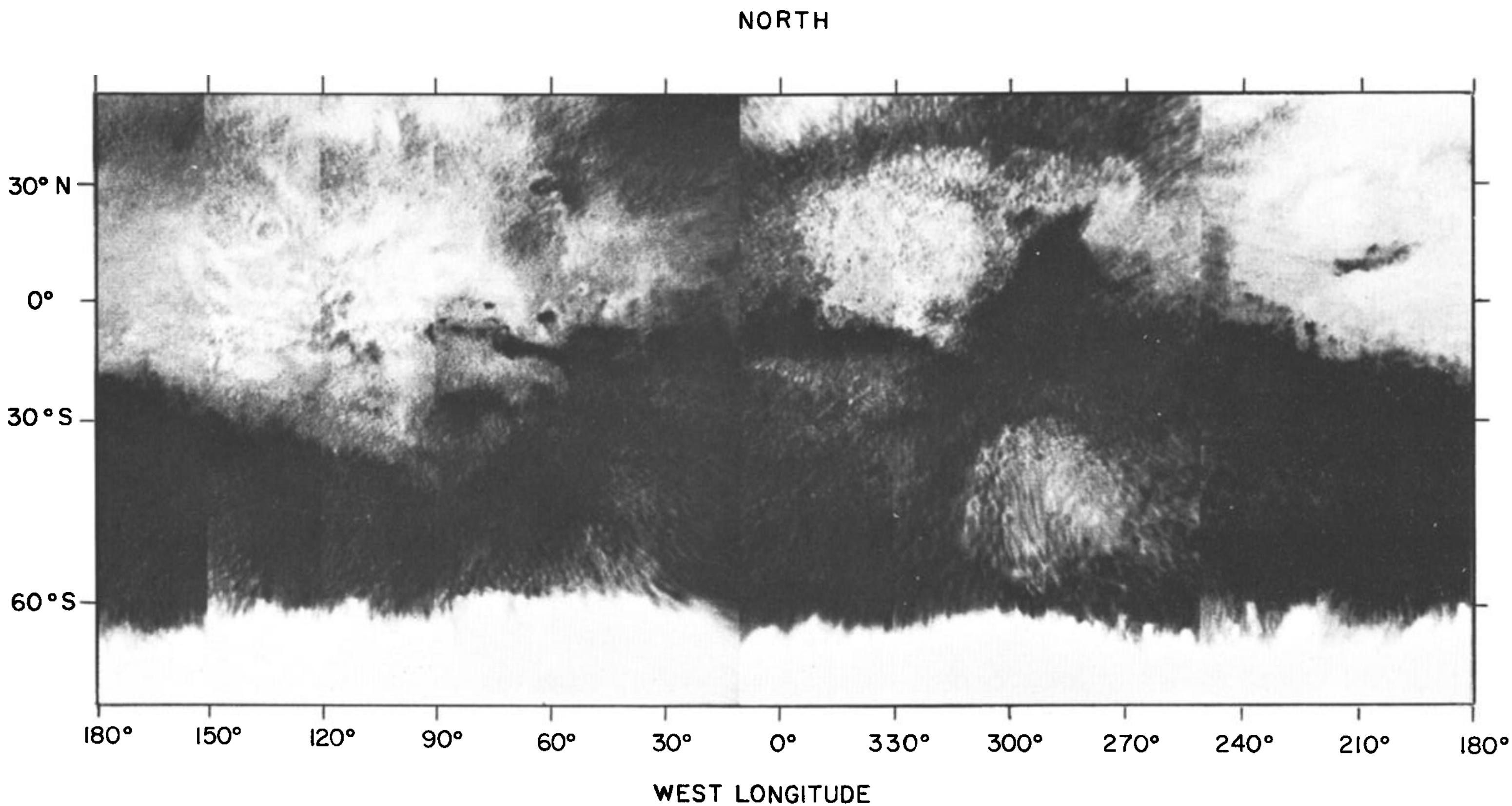

Fig. 2. A Mercator map of Mars. The photomap was assembled from nine far-encounter frames covering different areas of the planet. A part of each of these frames was transformed to Mercator projection by computer processing [*Cutts et al.*, 1971]. One degree of latitude on Mars corresponds to 59 km.

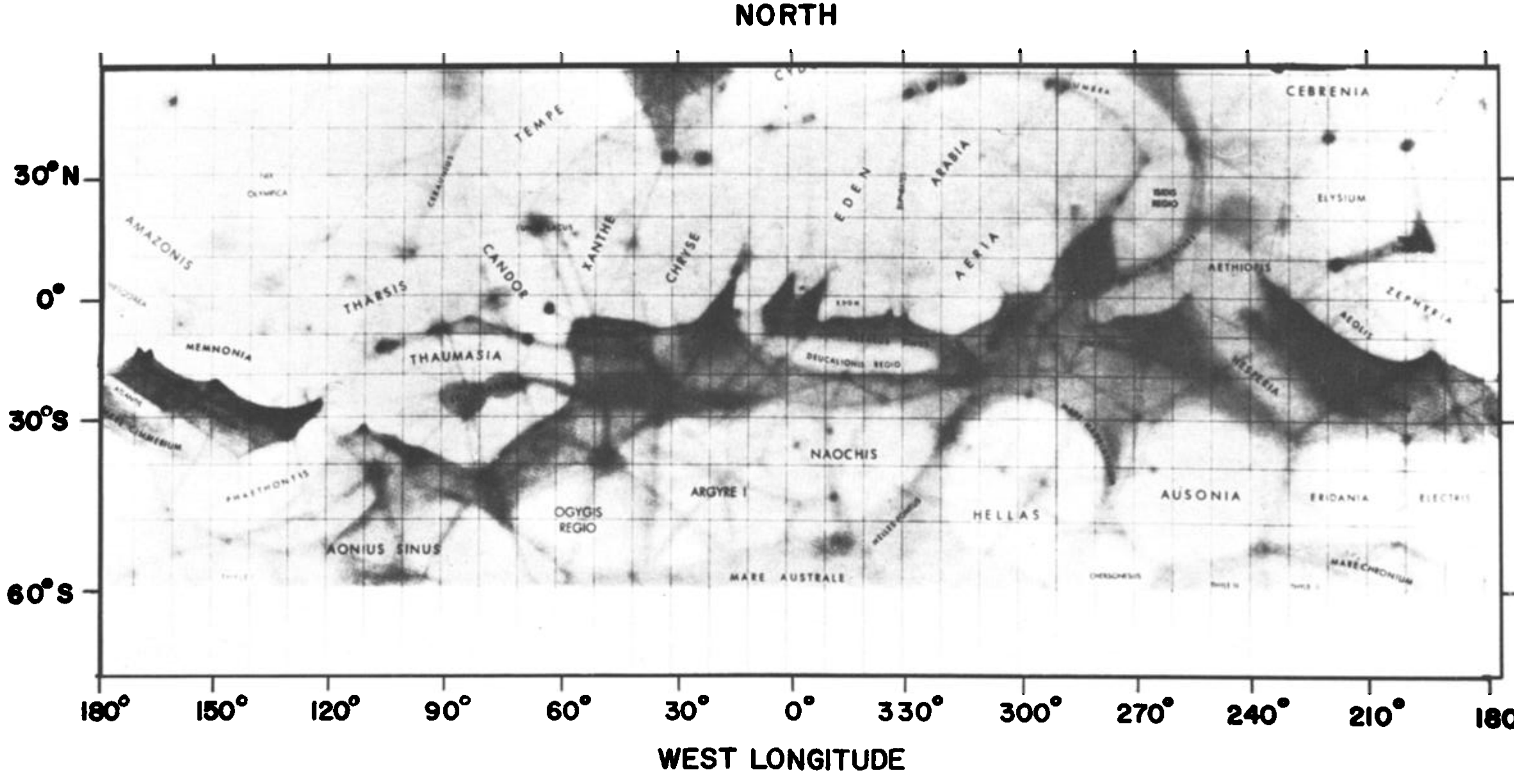

Fig. 3. Mars map: Projection for Mariner '69 encounter. This map was compiled by the Aeronautical Chart and Information Center, USAF, using telescopic drawings and photographs from the Lowell Observatory. Principal features were taken from 1954 telescopic photographs approximating the seasonal conditions expected at the time of the Mariner '69 encounter. Fine detail was taken from visual observations.

responding areas in the ACIC map we find either no detail at all or the stylized structure of dark blotches and lines typical of renditions of the canal network.

Despite its evident superiority in resolution, the Mariner map does not display any suggestion of the integrated network of dark lines recorded in the ACIC map. It is therefore evident that Mars more closely resembles the better telescopic photographs than the renditions of visual observers, and much of the 'fine detail' seen by some visual observers must be considered spurious. However, it is of interest to know if there are, nevertheless, linear markings of any kind in the regions where canals have been reported.

At the locations of some prominent classical canals we have identified features that possibly could have been mistaken for fine dark lines by a telescopic observer viewing a scintillating image. Both the classical canals Gehon (0°S, 0°W to 30°N, 20°W) and Ganges (5°S, 55°W to 20°N, 65°W) appear to be associated with contrast effects along the boundaries between bright and semi-tone areas (Figure 2). Other canals, notably Cerberus (10°N, 205°W) and Coprates (also known as Agathodaemon 10°S, 65°W) appear as elongate dark markings in the photomap (Figure 2). Curiously, the feature most resembling the canal networks in form is the fine structure of bright linear markings near Amazonis.

Mariner photographs reveal that the formless dark nodes known as 'oases' that were previously recorded, both photographically and visually, have fine structure. Circular, annular, irregular, and polygonal dark markings have all been recognized. Circular and annular markings may correspond to large individual craters.

Regional characteristics of light and dark markings. Both quantitative and qualitative methods can be used for investigating the regional characteristics of martian surface markings. Quantitative brightness data for determination of variations in color and photometric function over the planet are now available from the far-encounter pictures obtained by both the narrow- and wide-angle camera (Figure 4). Preliminary results indicate a greater diversity in surface materials than previously suspected [*Young and Collins*, 1971]. We confine our interests here to qualitative results based on the processed far-encounter frames.

The geometry of the major feature and boundaries is of significance. It is notable that the large bright features in the northern hemisphere, Arabia-Aeria and Elysium, have polygonal outlines, whereas the boundary of the light feature Hellas in the southern hemisphere, discussed in *Sharp et al.* [1971], has no discernible linear segments and is quite diffuse. Certain linear boundaries between features display parallel dark streaks; for example, Aeria and Syrtis Major (5°S, 300°W) and Moab and Sabaeus Sinus (5°S, 330°W). Other boundaries, such as Aurorae Sinus and Chryse (5°S, 40°W) and Mare Cimmerium and Aeolis (15°S, 220°W), are highly irregular, with projections perpendicular to or steeply inclined to the general trend of the albedo transition, and with dark outliers along the boundaries.

These differences in character of boundaries, while intriguing, permit us to do little more than

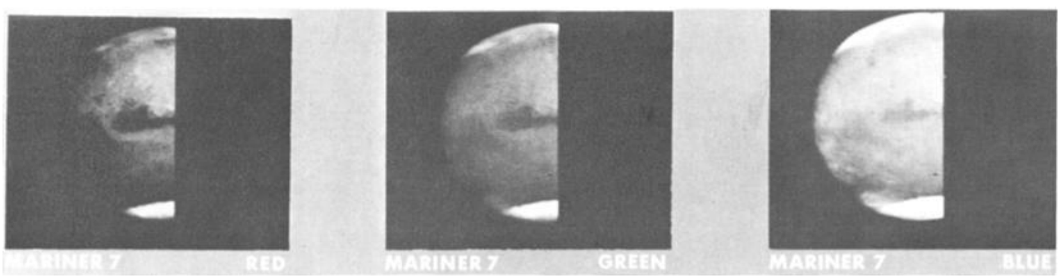

Fig. 4. Spectral contrast of light/dark regions. These images were obtained by the Mariner 7 camera A during the latter part of the far encounter. The bandpasses (red, green, and blue, respectively) were centered at approximately 0.58, 0.52, and 0.46 microns. All three images were processed identically; the decrease of contrast of Martian features with decreasing wavelength is apparent. Pictures were taken in the digital mode, trading off spatial resolution for photometric sensitivity.

Fig. 5. Variability of light/dark regions. These three telescopic photographs of Mars (made in 1954, 1937, and 1926) were taken in yellow light and show changes in Pandora Fretum and Deucalionis Regio, which are located immediately south of Meridiani Sinus–Sabaeus Sinus. The changes in appearance of Pandora Fretum do *not* reflect a seasonal progression. The 1937 photograph was taken earlier in the Martian season than either of the other photographs (Lowell Observatory photographs).

draw attention to those areas where further detailed exploration should be especially rewarding. Variations in the nature of boundaries may reflect differences in nature and origin and, in particular, the extent to which geological structure has been important in determining the shapes of features. Other features of particular interest in subsequent explorations will be those that have changed shape during historical time (Figure 5).

Correlations of light and dark markings with terrain. Three distinct types of terrain have now been identified on Mars: cratered terrain, chaotic terrain, and featureless terrain. They are described in *Murray et al.* [1971] and *Sharp et al.* [1971]. The relationship of each to light and dark markings is now discussed.

Cratered terrain is not uniquely confined to either light or dark areas. Some light areas, Deucalionis Regio for example, are just as heavily cratered as dark areas like Hellespontus and Meridiani Sinus (see Figure 9). Some cratered terrains cross light/dark boundaries without any perceptible change in crater density or morphology. On the moon the more heavily cratered uplands consistently have a higher albedo. A corresponding statement cannot be made for Mars.

Craters displaying light markings on floors, on walls, or on both are widespread on some dark areas, as for example, in Meridiani Sinus (Figures 7 and 8). In that area, these light markings are usually confined to the northern parts of the crater floors and to south-facing slopes. These albedo variations cannot be attributed to insolation variations (the sun is north of the zenith in Figure 7), nor can we imagine any plausible explanation involving variations in photometric function. Other craters displaying such albedo variations can be seen in the Mariner 4 frames 4N8 through 4N12 in Mare Cimmerium and Mare Sirenum [*Murray et al.*, 1971, Fig. 1].

Like cratered terrain, chaotic terrain is not exclusively associated with either a light or dark region. This is demonstrated by the comparison of a map showing areas interpreted as chaotic terrain on frames 6N5, 6N7, and 6N9 with the light and dark areas in the same region seen in far-encounter picture 7F69 (Figure 6). No unique correlation is evident. On a smaller scale, boundaries between chaotic terrain and cratered terrain are sometimes expressed by a distinct scarp [*Sharp et al.*, 1971] and are often accompanied by changes in reflectivity with lighter material on the lower side of the scarp.

The only featureless terrain recognized so far is entirely within Hellas, a light basin. The boundary with the dark area Hellespontus corresponds to the transition to cratered terrain [*Sharp et al.*, 1971]. This fact is insufficient to establish a genetic relationship, but it is certainly significant that the albedo boundary here marks the limit of the extremely active and recent modification process that has affected featureless terrain.

In summary, light and dark boundaries do not appear to be regionally correlated with either chaotic terrain or with cratered terrain boundaries. In both these terrains, however, there appears to be local topographic control of albedo markings as expressed by albedo variations in craters and along scarps. There is possibly

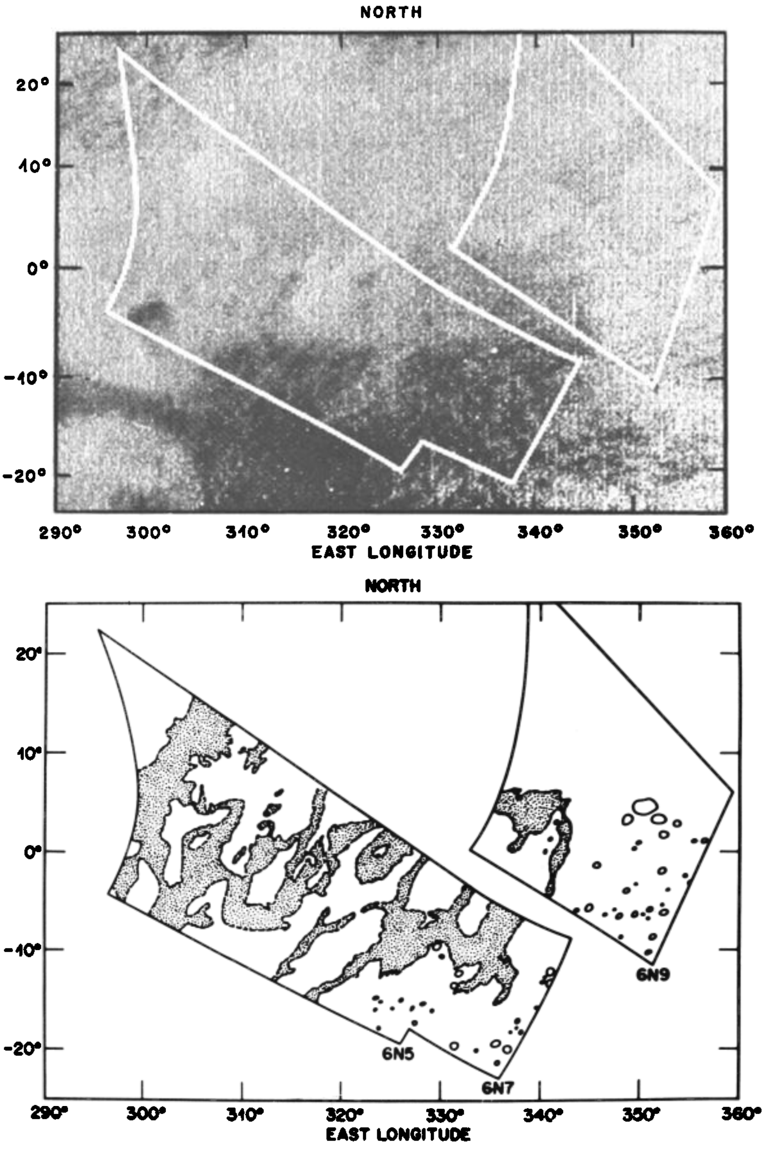

Fig. 6. Distributions of chaotic terrain and light and dark markings in photographs 6N5, 6N7, and 6N9. The distribution of light and dark markings (*top*) was taken from the Mercator photomap shown in Figure 2. The distribution of chaotic terrain (stippled) was obtained by extending boundaries of chaotic terrain recognized in B frames onto enclosing A frames [see *Sharp et al.*, 1971]. No correlation between chaotic terrain and light or dark markings is apparent. One degree of latitude of Mars corresponds to 59 km.

a genetic relationship between featureless terrain and a light region.

MERIDIANI SINUS–SABAEUS SINUS AND SURROUNDING LIGHT AREAS

Mariner 6 and 7 near-encounter photography provides detailed views of the equatorial dark region, Meridiani Sinus–Sabaeus Sinus, and bordering light areas. The details of the light and dark boundaries in this region are described here, and their implications for the genesis of light and dark markings are considered.

Description of boundaries. The boundary of Meridiani Sinus–Sabaeus Sinus with surrounding light areas is of unusually varied planimetric character. Three types of light/dark transition have specific relationships that can be recognized. First, the large polygonal crater Edom (Figures 7 and 8) defines the northern boundary of Sabaeus Sinus and the eastern boundary of Meridiani Sinus over a distance of almost 1000 km. The northeastern boundary of Meridiani Sinus continues northwest tangentially to the southwest side of Edom. The association of the wall and consequent elevation difference of this bright-floored crater with the light/dark boundary is one of the clearest examples of a difference in reflectivity associated with local topographic relief; the light area is low with respect to the dark area.

Second, between the dark area near Edom and the main body of Meridiani Sinus is a bright area (Figures 7 and 8). It displays one of the sharpest and most irregular boundaries seen in the Mariner photographs. Numerous small dark outliers are visible within the light area; similar detached light areas are not observed on the dark side of the boundary. It is noteworthy that along this sharp, irregular boundary, considerable albedo variation is seen in the light area, whereas the dark area has very uniform albedo.

Third, the brightness contrast between the western segment of Meridiani Sinus and the adjacent light area Thymiamata is diffuse. No topographic relief along that boundary is evident. It seems that here a lack of local topographic relief may result in a diffuse boundary.

In summary, the character of boundaries between light and dark areas in this region appears to be strongly influenced by local topography: along crater walls and scarps the boundaries are sharp, with light material on the lower side; in regions of no discernible topographic relief the boundary is diffuse. The dark region displays uniform albedo along sharp boundaries; the albedo of the light region is generally more variable.

Variation in crater appearance and abundance across boundaries. Bright markings associated with craters in the dark area Meridiani Sinus are striking and informative. Throughout this region light markings appear on the north side of crater floors and the south facing parts of crater walls and rims (Figures 7 and 8). The southern part of the floor and the remainder of the walls and rims are usually as dark as the surrounding terrain. The preferred location of these markings within craters is considered significant.

The extent of these albedo markings in large flat-bottomed craters changes gradually across an albedo boundary. This is displayed in frames 6N11 and 6N13 (Figure 7). In crossing the diffuse boundary from Meridiani Sinus to light Thymiamata (6N11) the light markings become more extensive, covering greater portions of the walls and floors of the crater. Farther into the light area, only a small dark patch on the southern part of the floor remains; still farther, dark markings disappear altogether. These relationships suggest the possibility that the light materials surrounding craters in the light region and occurring inside craters in both light and dark regions are of the same nature and origin.

Variations in the density and morphology of large flat-bottomed craters across light/dark boundaries presumably record differences in surface modification that have occurred since the formation of the craters. Figure 9 shows crater-size-frequency distributions obtained for Deucalionis Regio and the dark region, Meridiani Sinus–Sabaeus Sinus just north of the light/dark boundary in 6N13, 6N19, and 6N21. The similarity in amplitude and form of these curves shows that, at least across that boundary, the topography has been modified to the same degree in both light and dark areas. Craters identified in Mariner 6 maximum discriminability A frames are traced in Figure 10. Although abundances in light Deucalionis Regio are similar to those in dark Meridiani Sinus–Sabaeus Sinus, light areas in the northern parts of 6N9, 6N11, and 6N13 show fewer craters. B

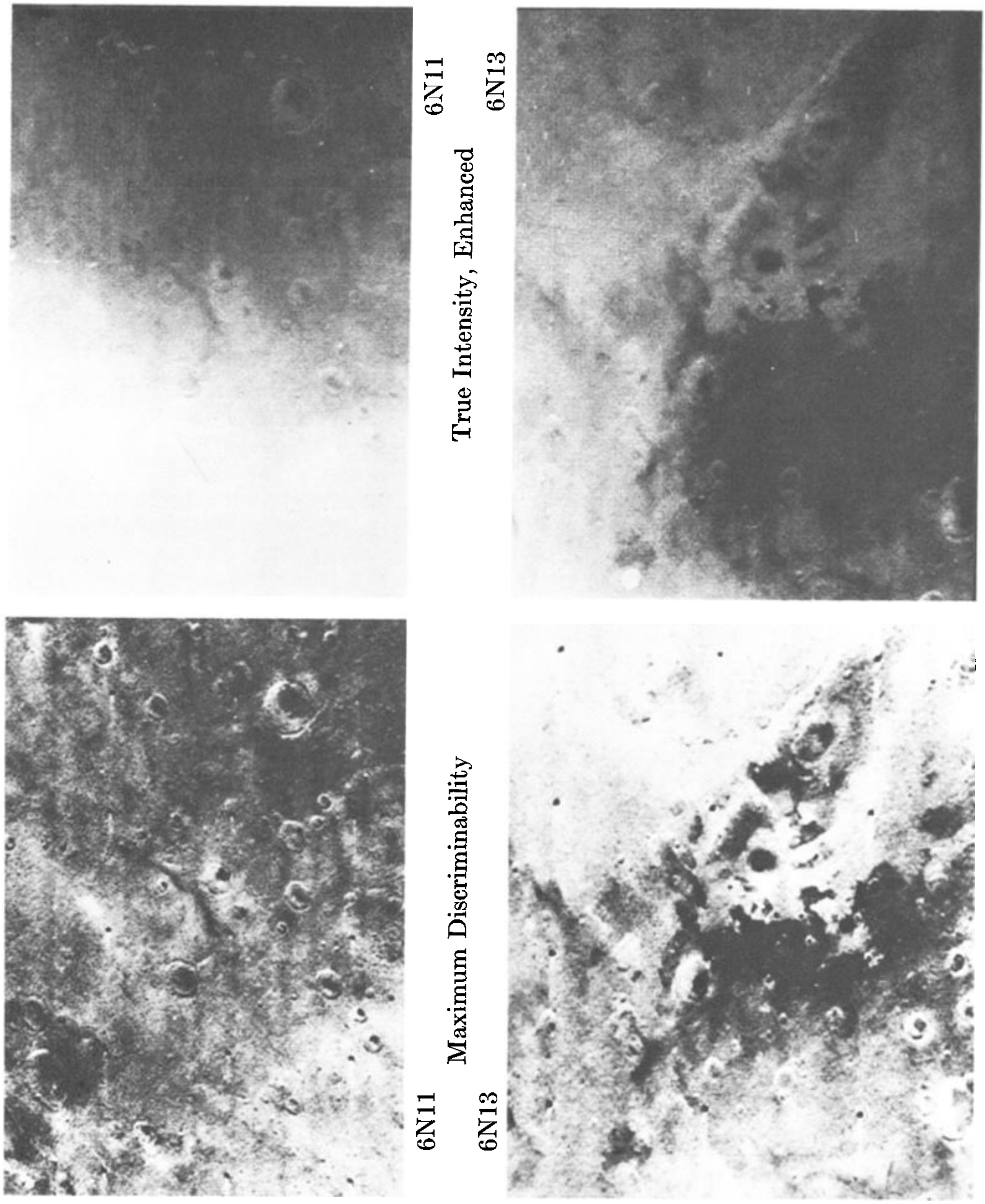

Fig. 7. Mariner 6 frames of the northern boundary of Meridiani Sinus. Frames 6N11 and 6N13 display the variation in planimetric character of a light/dark boundary and the changed appearance of albedo markings in craters across that boundary. The large crater Edom is located in the light area at the eastern edge of 6N13. Maximum discriminability versions have been processed so as to suppress regional albedo variations and to drastically enhance small-scale variations in intensity. Thus light/dark transitions are less easily displayed on those versions, whereas albedo variations within craters are easily seen. The true-intensity versions are included to better display the distribution of light and dark regions. The solar elevation angle varies from 52° in the southwest corner of 6N11 to 14° in the northeast edge of 6N13. The east–west dimension of the sections of each frame shown here is about 800 km.

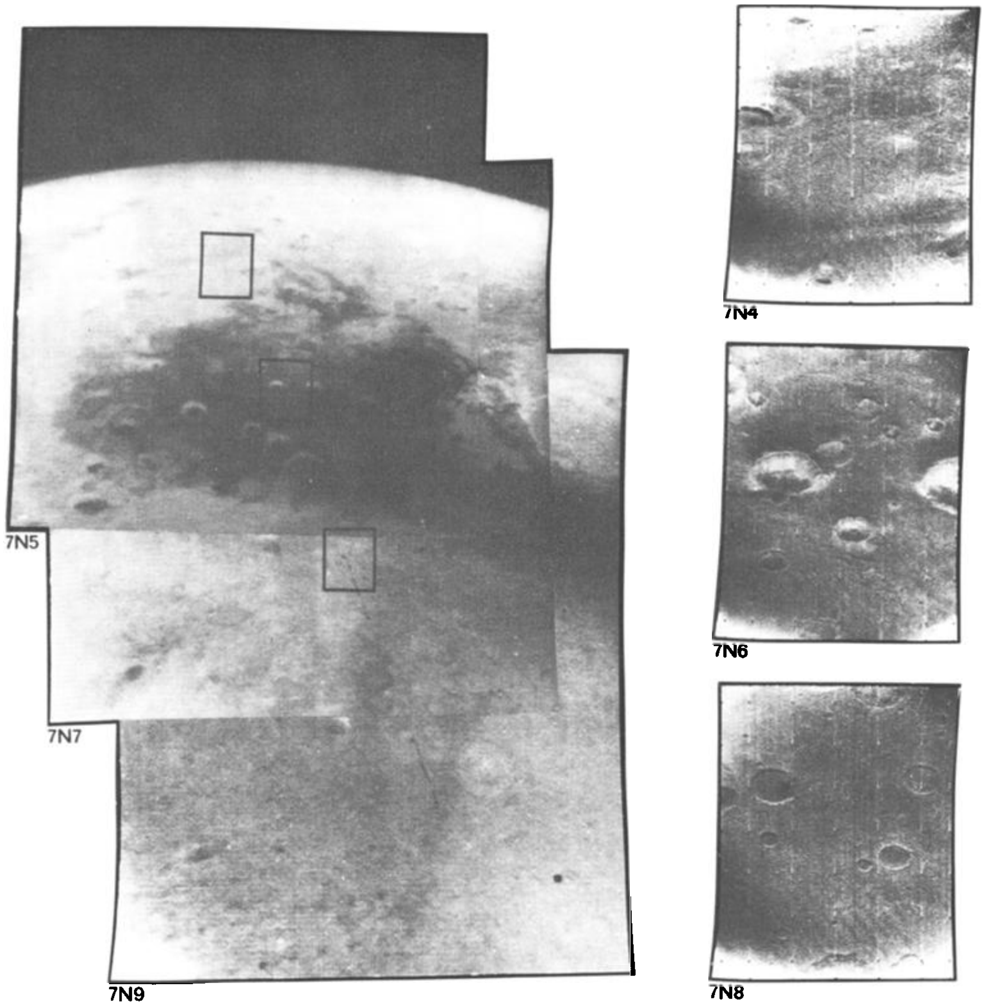

Fig. 8. Mariner 7 mosaic of Meridiani Sinus–Sabaeus Sinus and surrounding light regions. The direction of view is approximately NNW. The center of the lower edge of 7N9 is located at 15°E, 35°S; the center of the limb in 7N5 is 350°E, 35°N. The dark area, Meridiani Sinus–Sabaeus Sinus lies along the equator. The crater Edom is in the northeast corner of 7N9. The east–west dimension of the mosaic ranges from 1200 km across the base of 7N9 to about 2000 km along the limb. The solar elevation angle ranges from 90° in Meridiani Sinus to 48° in the southern part of 7N9. Positions of the B frames 7N4, 7N6, and 7N8 are outlined in the mosaic. The A frames 7N5, 7N7, and 7N9 were taken with red, green, and blue filters, respectively. As the contrast of light and dark markings is highest in the red and lowest in the blue, these pictures have been contrast-enhanced differently before assembling the mosaic. Other visible features in this region are identified in Figure 10.

frames 6N10, 6N12 confirm this impression of a difference by showing that older, flat-bottomed craters are greatly obscured in these northern light areas, although bowl-shaped craters are fresh.

Craters in the Mariner 7 B frames (Figure 8) in the northern light area (7N4) are more subdued than in either dark Meridiani Sinus (7N6) or light Deucalionis Regio (7N8), where craters appear morphologically similar.

In summary, differences in crater abundance do not appear to correlate uniquely with light/dark boundaries. Across some light/dark boundaries the crater abundances and morphologies

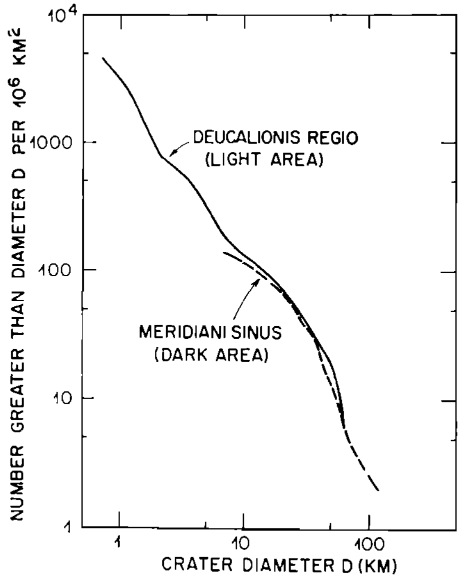

Fig. 9. Comparison of crater abundances in Meridiani Sinus and Deucalionis Regio. The number of craters per 10^6 km^2 with diameter larger than D is plotted for the dark area just north and the light area just south of the Meridiani Sinus–Sabaeus Sinus/Deucalionis boundary. Frames 6N13, 6N19, and 6N21 were used in compiling these crater-size-frequency distributions. No B frames were located in the dark area near the boundary; therefore, counts for the dark area do not include craters smaller than about 10 km.

appear unchanged; across others the crater abundance in light areas is lower. The variations in the appearance of craters displaying albedo markings across light/dark boundaries suggest that the light material in craters in the dark area is the same as the material at the surface of the light area.

Discussion. The observations made from Mariner 6 and 7 of the equatorial dark region, Meridiani Sinus–Sabaeus Sinus, and surrounding light areas, provide new information relevant to the nature of the surface markings. The markings are on the surface and must correspond to differences in material texture, composition or particle size. We do not address the question here of what these differences are—whether there are distinct sources for light and dark materials or whether one is merely an altered form of the other. Rather we discuss how and when the local albedo markings within craters were formed and the dark feature Meridiani Sinus–Sabaeus Sinus came to have its present boundaries.

Murray et al. [1971] concluded that the large flat-bottomed craters have suffered intense modification involving significant horizontal redistribution of material. It is unlikely that the sharp albedo boundaries now visible along the eastern boundary of Meridiani Sinus and also within the craters on this dark feature could have survived such dramatic leveling of topography. Evidently, the detail observed along such boundaries must have developed after the large flat-bottomed craters were modified.

A most significant observation is that at least across one boundary (northern boundary of Deucalionis Regio), the morphology and abundance of large flat-bottomed craters remains unchanged. The light/dark contrast across this boundary cannot have resulted from the kind of mare-filling processes operative on the moon; these processes would have flooded and obscured the old flat-bottomed craters.

Surface processes that might produce the observed albedo variations can be divided into those that involve transport and deposition and those in which materials are chemically or physically altered in situ involving particle-size variations, thin coatings, or even hypothetical microbial growth and disappearance. It is difficult on the basis of present information to evaluate clearly all these possibilities. It is our opinion, however, that transport, either regional or local, is implied by the strong preferred orientation of the light and dark patches in craters, the association of light markings with south-facing slopes in Meridiani Sinus, the correlation between local topographic relief and sharp albedo boundaries, and the peculiar transition in albedo markings in craters across some light/dark boundaries. It is difficult to imagine what in situ processes would produce features with such a strong bias in location and sensitivity to local topography.

If transport played a role in creating the observed distribution and configuration of light/dark markings, the question remains as to which material was transported. Without knowledge of the transportation mechanism, the photographic interpretation is inconclusive on this point. If we assume that deposition occurs in local topographic lows, several lines of evidence point to the light material being mobile.

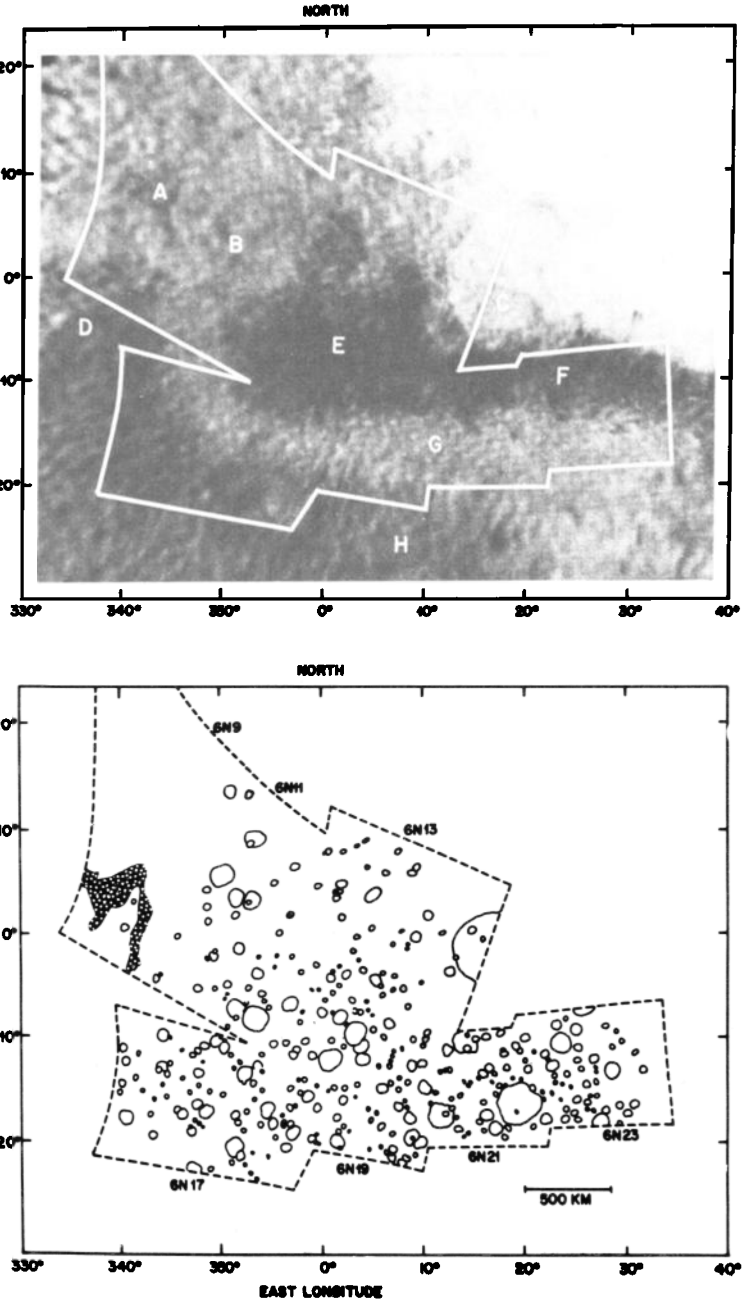

Fig. 10. Distribution of craters and light and dark markings in the Meridiani Sinus region. Variations in crater abundances across light/dark boundaries are illustrated. The distribution of light and dark markings (*top*) was taken from the photomap of Figure 2. The contrast in the western part of this section is poor because it was photographed very close to the morning terminator. The features identified are: A, Oxia Palus; B, Thymiamata; C, Edom; D, Margaritifer Sinus; E, Meridiani Sinus; F, Sabaeus Sinus; G, Deucalionis Regio; H, Pandora Fretum. The distribution of craters (*bottom*) is derived from maximum discriminability versions of Mariner near-encounter frames such as those of Figure 7. Chaotic terrain (stippled in frame 6N9) is also displayed, but albedo markings and other topographic forms visible in these frames are not shown.

First, the dark area Meridiani Sinus is a regional high with the center 2–3 km above surrounding areas [*Herr et al.*, 1971]. Then, on a local scale, light material resides at a lower elevation when boundaries are coincident with topographic relief. Finally, detached dark outliers are seen on the light side of a sharp irregular boundary.

It is natural to consider that wind on Mars might be the transport mechanism involved in redistributing material. Episodic events on Mars and seasonal and secular changes have been attributed to wind previously [*Kuiper*, 1957; *Rea*, 1964; *Sagan and Pollack*, 1969]; hence the idea of singificant meteorological activity on Mars is not a new one. Whereas atmospheric suspension of material may well occur on Mars and indeed is a possible explanation of some seasonal changes and episodic events, deposition from suspension may be inadequate as an explanation of the details of albedo boundaries. It is difficult to imagine how the gradual settling of suspended 'dust' could create sharp albedo boundaries and reflect topographic control. If aeolian transport of light material *into* Meridiani Sinus has produced the observed albedo markings, it probably operates in some fashion similar to traction and saltation that occur on earth. It is conceivable, however, that this dark area was once completely covered by light material. Transport of material *out of* Meridiani Sinus, could perhaps be accomplished by suspension as well as traction and saltation.

If we accept that transportation and deposition by wind action has occurred on Mars, it is tempting to speculate that this has contributed to the modification of topography. Geographic variations in crater morphology and abundance in the vicinity of Meridiani Sinus (Figure 10) might be attributable to such effects.

COMMENTS PERTINENT TO THE MARINER 1971 MARS MISSIONS

The Mariner orbiter flights of 1971 offer opportunities to clarify and extent the observations discussed in this paper. Other major light/dark boundaries should be viewed for evidence of topographic control. To elucidate the possible relationship of the degree of modification of cratered terrain and albedo markings, high-resolution pictures across albedo boundaries will be essential. These pictures will permit a determination of whether permanent light areas on Mars are those areas where cratered terrain is most heavily modified. It will be interesting to look for changes in the local albedo markings within craters. Observations of these local features may give further insight into the nature of the major seasonal changes in the light and dark areas.

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